A meta-analysis on the effectiveness of collaboration in game-based learning

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Abstract—Game-based learning (GBL) can be used to improve learning outcomes. A common component of GBL is collaboration. While research has shown that GBL is frequently utilized to improve student motivation and learning outcomes, there is inconclusive research regarding the effectiveness of collaboration compared to individual or competitive play. In this meta-analysis, four articles written from 2013 to 2020 showed that collaborative GBL was more effective than individual GBL at improving learning outcomes with an average corrected effect size of 0.133. This study also identifies a gap in recent research and offers suggestions for future research.

1 INTRODUCTION

In schools and at home, there is a strong history of leveraging games to improve learning outcomes (Pierson, 1983). Game-based learning (GBL) has become a popular and effective way to provide a more engaging learning environment (Dickey, 2006; Doumanis et al, 2019; Reynolds, & Taylor, 2020). Student test scores typically show a significant improvement after participating in GBL (Jenkins et al, 2003; Riopel et al, 2019; Sailer, & Homner, 2020; Sung & Hwang, 2013).

Though there are many elements of GBL which contribute to this increase, some game design elements are exclusive or conflicting. These design considerations range from game genre and play style to whether the game has collaborative or competitive social interactions. These limitations have led researchers to claim there is value in determining which elements of GBL are the most impactful (Filsecker & Hickey, 2014; Plass et al, 2013).

In this meta-analysis, collaborative game-based learning is researched and compared against solitary game-based learning to determine the effectiveness of collaboration on increasing student learning outcomes.

2 RELATED WORK

Within the classroom, gamification has been a part of learning for hundreds of years (Pierson, 1983). GBL has been used at all educational stages (Hainey, Connolly, Boyle, Wilson, & Razak, 2016). When people learn, the level of contextualization of their subject or task impacts the depth of knowledge acquired (Plass et al, 2013). The two most valuable aspects of gamification are that they provide motivation and context (Devoe, 2018; Eyupoglu, & Nietfeld, 2019; Palomino et al, 2019) across many different backgrounds and cultures (DiSalvo et al, 2008). Studies suggest GBL is a powerful pedagogical tool which can allow for deeper learning than traditional lecture-based learning (Barab, 2009; Plass et al, 2013). Some research has shown it is also effective at decreasing the cognitive load of learning (Chang, Shih, & Chang, 2017). Learning through play is a critical part of early education, and gamification in learning is the formalization and research of how to structure play to optimize learning outcomes (Smidt, 2010; Smith, & Pellegrini, 2008).

One important element of GBL is collaboration (Bakan, & Bakan, 2018). Recent studies have shown that collaborative game-based learning (CGBL) can positively impact learning outcomes (Jagušt, Botički, & So, 2018; Van Coller, 2018). Participation in collaborative game-based learning has shown improvements in student engagement as well (Klopfer, 2005b). Cooperative games have also been shown to increase motivation of at-risk students (Hanghøj et al, 2018). However, some research shows that collaboration is less effective than individual or competitive play (Jagušt, Botički, & So, 2018; Ruipérez-Valiente, & Kim, 2020). As such, the effectiveness of collaboration in GBL requires additional investigation.

The following section contains a literature review of articles used in this meta-analysis, with a focus on their methodology and results.

2.1 Recent research into collaborative game-based learning

2.1.1 The developmental influence of collaborative games in the Grade 6 mathematics classroom

This study is focused on the practical application of collaborative games to promote mathematics learning. The influence of collaborative games on both hard and soft skills were investigated, including but not limited to mathematics knowledge, competence, creativity and appreciation of math. The intervention group completed a post-lecture game-based learning exercise, while the control group completed a post-lecture activity from their textbook.

The experiment's participants consisted of one mathematics teacher and the students of four Grade 6 classrooms, with 28 students in the intervention group and 23 students in the comparison group. The mathematics teacher acted as the facilitator involved in administering the tests and guiding the activities. The research was done over the period of one week, with four mathematics topics covered.

The results of the study show that students in the intervention group experienced a greater post-test percentage increase than students in the comparison group. The difference between pre and post test scores was +13.85 for the intervention and +9.57 for the control. From this, the conclusion is that collaboration has a significant positive effect on learning outcomes. Additional results may be found in the paper regarding which areas of mathematics were most affected by this experiment.

2.1.2 Examining competitive, collaborative and adaptive gamification in young learners' math learning

This is an empirical study on the impacts of competitive, collaborative and adaptive game-based learning for second and third-grade students. The focus of this research is based first on finding how these types of gamification affect the students engagement and performance levels, and second on how different elements of gamification such as badges and leaderboard affect engagement and performance.

The study included three participating classrooms, composed of three teachers and 54 students. Each class participated in four lessons, covering the four game conditions. The experiments were conducted on a tablet, using a simple mathematics game.

The results of this study confirm the notion that different elements of gamification have different impacts on student performance and motivation. Guidance is provided to teachers on simple but effective tools which can be used in their classrooms to gamify mathematics lessons.

2.1.3 The Impact of Individual, Competitive, and Collaborative Mathematics Game Play on Learning, Performance, and Motivation

The goal of this research is to determine how different modes of play impact students learning outcomes, performance and motivation. There is a secondary focus on the context of learning and achievement goal theory. The authors are seeking to validate claims that games are good for learning.

In this study, 58 students in grade 8 participated in this research, along with one teacher. 16 students participated in the individual group, 20 in the competitive group and 22 in the collaborative group. Each student played a five minute practice round to familiarize themselves with the game and controls. The pre-test consisted of a 3 minute round played individually. Participants then played a 15 minute session in their assigned mode of play. The post-test was another 3 minute round played individually.

The results of this study show no statistically significant difference in post-test scores between the different conditions. This may be due to the short duration of the experiment which occurred over a single day. Individual and competitive modes of play lead to the highest motivation, while collaborative play lead to the highest interest in playing the game again.

2.1.4 A collaborative game-based learning approach to improving students' learning performance in science courses

This study is focused on evaluating the effectiveness of using a collaborative game-based learning environment to increase students' performance and motivation. The researchers expanded on past research into "Mindtools" which are defined as "computer applications that engage students in critical thinking" (Sung & Hwang, 2013). They developed an educational computer game based on this concept.

The participants of this study were from three classes of sixth graders. There were three groups, each with 31 students. Two science teachers administered the pre and post tests.

Conclusions were drawn from the use of analysis of covariance (ANCOVA). The study showed that conventional CGBL was 2.2% less effective in terms of post-test results and overall was less effective than individual GBL.

3 METHODOLOGY

In order for a review to qualify as a systematic review, it must use systematic methods to collect data, critically appraise research studies, and synthesize findings in order to provide a complete, exhaustive summary of current evidence. In this paper, five steps were taken in order to create the systematic review and meta-analysis. These steps were based on the article "How to conduct meta-analysis: A Basic Tutorial" by Arindam Basu.

First, The reviewer must create a clear, concise question, identify relevant studies to the question, and appraise their quality (Khan, Kunz, Kleijnen, & Antes, 2003). Two additional steps were taken to extend the systematic review to a meta-analysis: Information was abstracted from these appraised articles and a statistical synthesis was created.

3.1 Frame the question

For framing an answerable question in a meta analysis, consideration must be given to what focus, comparative elements and outcomes are of interest. One approach to creating focused, answerable questions is the "Participant -Intervention-Comparator-Outcomes" (PICO) framework (Schardt et al., 2007). For this research, the following values were used:

P: Students, of any sex, ethnicity, and nationality
I: Collaboration
C: Competition, Or individualist learning
O: Standardized Test Scores, or Generalised Learning Outcomes

The specific question this leads to is as follows: "Among students, compared with all other game-based learning approaches, what is the effectiveness of collaboration for improving learning outcomes?"

3.2 Conduct a search

The next step is to utilize the stronger criteria of the refined question in order to define search terms and conduct a search. The articles used in this paper were found through Google Scholar. The specific search terms used were:

Collaboration AND Student AND "Game based learning" AND quantitative AND "learning outcome" OR "learning outcomes" OR "test score"

This set of search terms returned approximately 3870 articles which may have relevance to the question. The potential relevance of these studies must be examined, and only studies directly relating collaboration in game-based learning in comparison to either competition or individual learning are included in the final set.

3.3 Select the articles

In order to document the articles reviewed during this process, both an inclusion and an exclusion schema were created to record the reasons behind accepting or rejecting articles. The schema used was as follows:

The following inclusion criteria was used for this meta-analysis:

- Studies dated from January 2012 to September 2020.
- Empirical research focused on GBL.
- Research presents results which measure relationships between collaborative GBL and learning outcomes.

Thee following exclusion criteria was used for this meta-analysis:

- The article is irrelevant for the study question
- The article has an irrelevant population
- The article has an irrelevant intervention
- The article has an irrelevant comparison group
- The article has an irrelevant outcome
- The article is published in a non-standard format
- The article is not available in English
- The article is a duplicate of a previously reviewed article

Using this schema, the title and abstract of each article in the search results are analyzed, and either rejected or moved to a second list containing articles whose full text needs to be reviewed. From this list, each article is critically appraised for relevance and quality. Finally, in order to keep the work transparent, replicable and extensible, a report on these rejections should be compiled. (PRISMA, 2015) A framework for performing this documentation is the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA) chart, which can be created through the data associated with the above schema.

3.4 Abstract the data

Once the final set of articles has been determined, the data from each study needs to be abstracted. From each study, the following information was gathered:

1. The title of the article
2. The name of the first author
3. The year the article was published
4. The type of research
5. The study's population
6. The study's intervention
7. The study's comparison condition(s)
8. The measured outcome
9. The number of participants in the intervention
10. The number of participants in the competitive comparison
11. The number of participants in the individual comparison
12. The mean of the intervention outcome
13. The standard deviation of the intervention outcome
14. The mean of the competitive comparison outcome
15. The standard deviation of the competitive comparison outcome
16. The mean of the individual comparison outcome
17. The standard deviation of the individual comparison outcome
18. The quality of the article

The specific information used in this abstraction will be unique to each meta-analysis. For this research, the above components were sufficient. This information is then used to create a series of statistical syntheses for the meta-analysis and create numerical and graphical presentations of the data.

3.5 Create a statistical synthesis

The final step of this process is to create a statistical synthesis, and interpret the findings. A good meta-analysis will also look at the strength and consistency of the evidence, and investigate reasons for any inconsistencies. The types of questions which will be discussed in the results section are: Were the findings statistically significant? How many articles had positive, negative or neutral correlations between the intervention and comparison(s)?

4 RESULTS

During this research, a refined search which is detailed in the methodology section above yielded approximately 3870 articles for consideration in the meta-analysis. Due to the single semester time constraints, a total of 998 articles were screened for eligibility. This set was run through the inclusion and exclusion criteria and five articles were found to be acceptable for the meta-analysis. Additional information on this process can be found in the PRISMA chart below.

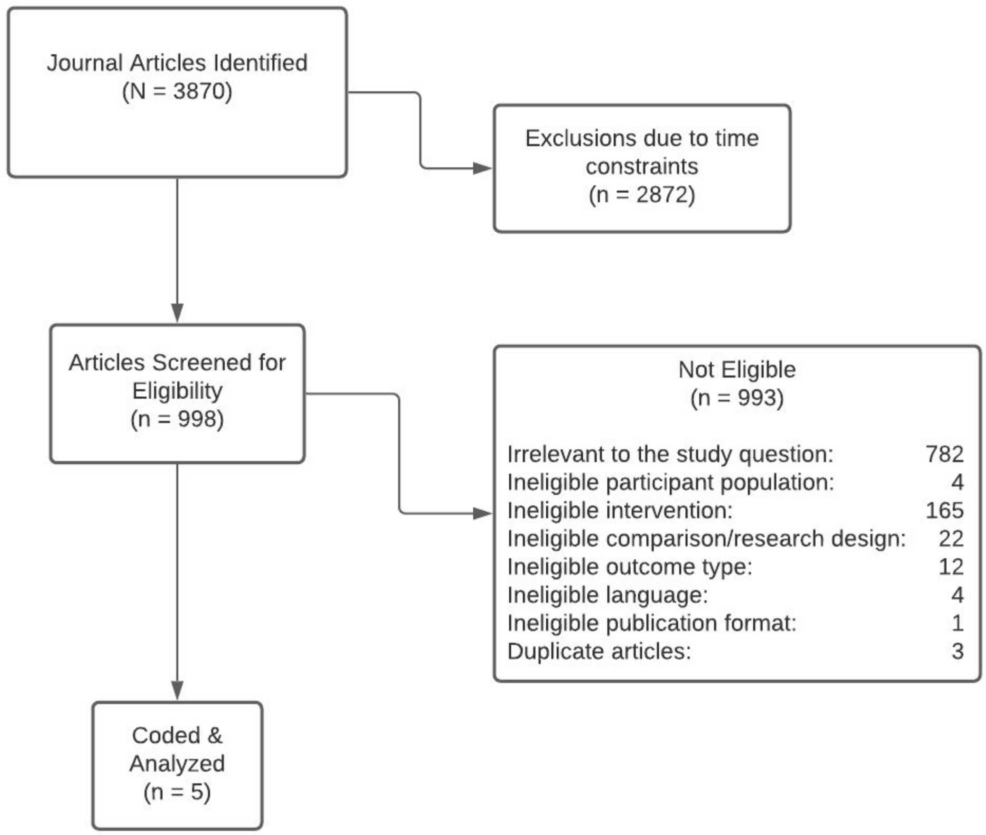

Figure 1— A PRISMA chart detailing aggregate reporting on the article collection process.

After additional analysis of the five articles, only four were able to be abstracted into the data required for meta-analysis. Angelique van Coller wrote an excellent research article titled "The developmental influence of collaborative games in the Grade 6 mathematics classroom" which despite containing a breadth of research regarding collaboration in game-based learning was not included in the final results due to the lack of reporting on standard deviation in mean results. A narrative review of articles read during this process echo the results of other meta-analyses which examine game-based learning in that there is a significant positive effect on learning outcomes or student achievements when comparing game-based learning to traditional textbook and worksheet learning (Karakoç, Eryılmaz, Özpolat., & Yıldırım, 2020; Tokac, Novak, & Thompson, 2019). In this meta-analysis, four articles written from 2013 to 2020 showed that collaborative GBL was more effective than individual GBL at improving learning outcomes with an average percentage increase of 2.13, and an average corrected effect size of 0.133. Additional information on these numbers can be found in Figure 2 and Figure 3 below.

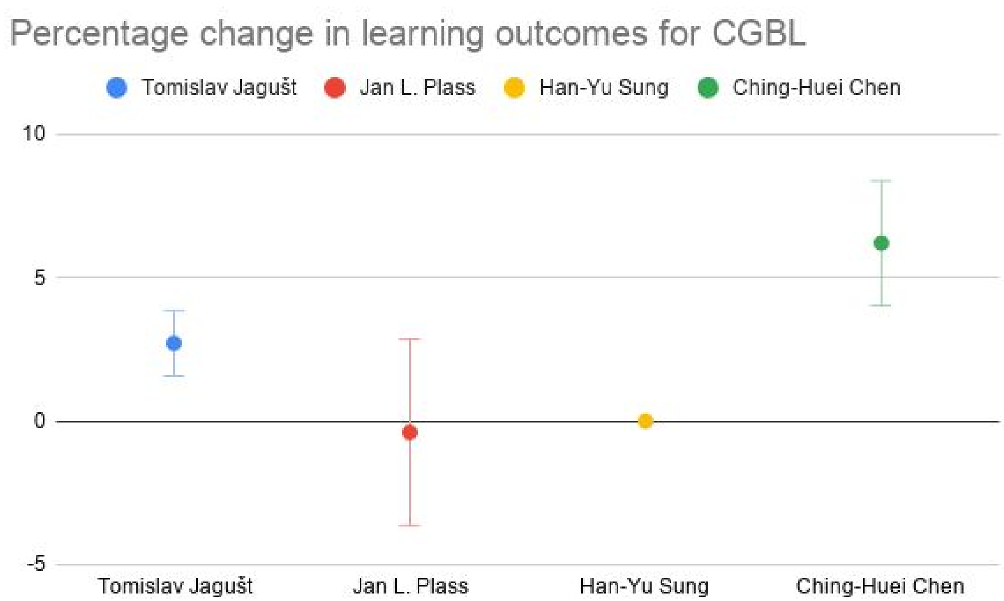

Figure 2— The observed difference in learning outcomes between collaborative and individual game-based learning. The average change displayed in this chart is 2.13%

As the sample size for these studies was fairly low, with an average group size of 31.4, the Hedges' g formula was used to calculate a corrected effect size.

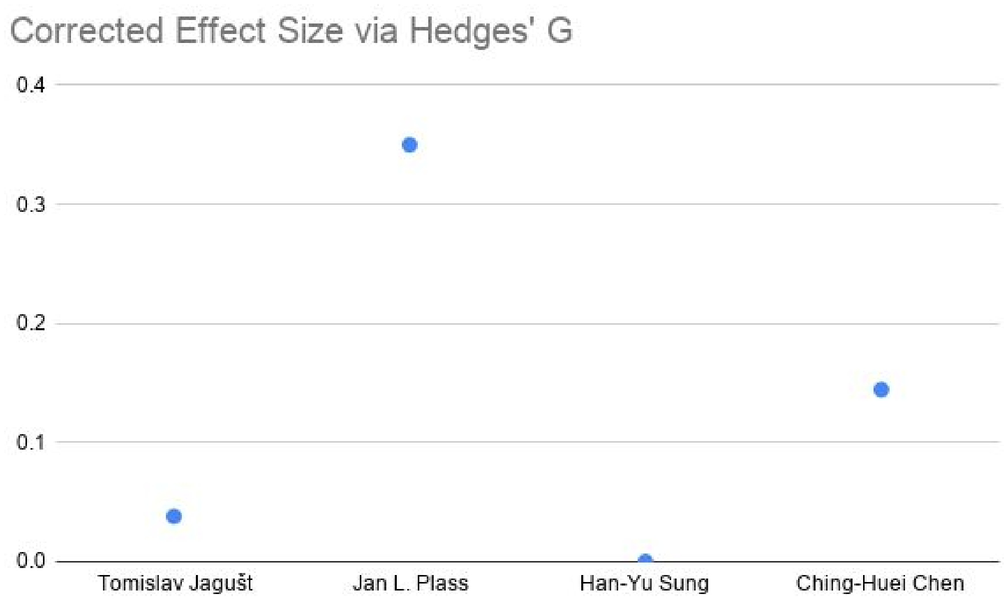

Figure 3— The corrected effect size of each study, calculated via Hedges' G. The average value displayed on this chart is .133

The final results of this meta-analysis are inconclusive. From the current data, using collaborative game-based learning has a small positive effect on student learning outcomes. However, only four studies were found for analysis between 2012 and 2020 which directly compared collaborative and individual GBL. Additional empirical research is needed before statistically significant results can be drawn.

5 LIMITATIONS

The major limitations of this research are the time frame, the lack of exhaustive article review, and the lack of analysis on the impact of moderators such as sample size, grade level, study length and game design elements. Collaborative game-based learning may be affected by a number of moderators such as domain subjects, game genres, gameplay styles and student grade level.

Additionally, there are multiple forms of collaboration. This research did not distinguish between in-game collaboration between multiple user avatars and out-of-game collaboration such as two students sharing one game.

6 CONCLUSION

As highlighted in the results section, there are other systematic reviews and meta-analyses which examine game-based learning (Karakoç, Eryılmaz, Özpolat., & Yıldırım, 2020; Tokac, Novak, & Thompson, 2019). However, there is comparatively little research which contains collaboration as the intervention and either competition or individual play as the comparison. The results of this meta-analysis identify but do not address this gap in game-based learning.

The initial intention of this research was to expand upon previous research and include results regarding the impact of moderators such as game design characteristics (Lameras, Arnab, Dunwell, Stewart, Clarke, & Petridis, 2017). and differences in instructional interventions (Vandercruysse, & Elen, 2017). However, the studies identified during research provided incomplete information which prevented this analysis.

Given how few empirical studies were published since 2012 to determine the effect of collaboration in GBL, this study echoes other research in the field that there is a continuing need for more research to examine how video games affect student learning outcomes.

7 FUTURE WORK

Due to the limited sample size of the meta-analysis, replication or extension is required before any statistically significant conclusions can be drawn.

The work done in this paper could be extended to be an exhaustive review of articles published between 2012 and 2020. Only 1000 of approximately 3870 articles were reviewed in this paper, however efforts were taken to ensure this work would be extensible and reproducible.

Additionally empirical research in the area of game-based learning is needed, especially on either collaboration or on how different game elements impact learning outcomes. A controlled trial between some collaborative game vs a solo experience would be valuable to future meta-analyses on this topic.

Future research could also examine the impact of different moderators on the effectiveness of collaborative game-based learning.

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